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FISHERIES MANAGEMENT AND THE LIMITATION OF FISHING

by

J. A. Gulland

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1969

ROBERT A. SKILLMAN

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and

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y

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FISHERIES MANAGEMENT AND THE LIMITATION OF FISHING

by

J.A. Gulland
Chief, Fish Stock Evaluation Branch

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, December 1969

PREPARATION OF THIS PAPER

This paper gives some results of studies on the problems of fishery management being carried out by the Fish Stock Evaluation Branch and other units of FAO. It is hoped that these studies of general problems will assist and complement the work of regional fisheries bodies and others concerned with solving specific problems.

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FISHERIES MANAGEMENT AND THE LIMITATION OF FISHING

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1. INTRODUCTION

Direct experience in many fisheries, confirmed by theoretical studies, has shown the serious effects that uncontrolled fishing can have on fish stocks, and on the fisheries based on them. The scientific studies have shown the value of proper management and regulation, and that management measures can be divided into those controlling the total amount of fishing, and those affecting the size or other characteristics of the fish caught (e.g. size limits, minimum mesh sizes of trawls, etc.). This note is only concerned with the first of these.

The biological consequences of control of the amount of fishing have been well described in a number of papers (Beverton and Holt 1957, Schaefer 1954) and do not need repeating in detail. However, although it has been the common experience of bodies concerned with fisheries management that the practical and economic consequences of measures taken to limit the amount of fishing have often been much less beneficial than the simple biological analysis would predict, few studies have been made of practical difficulties of limiting fishing. Some of the more obvious problems, e.g. of a greatly shortened season with a single quota system have of course become widely appreciated.

The biological reasons for wishing to control fishing can be directly shown by a simple curve relating the amount of fishing, strictly the fishing mortality coefficient, to the average long-term catch taken by that fishing mortality. The precise form of this curve will vary with the stock of fish concerned, and with adjustments that may be made to the composition of the catch (e.g. by mesh regulation), but it will generally lie between the two extremes shown in Figure 1 - (a) a curve with a pronounced maximum, and a sharp fall for rates of fishing beyond the maximum, and (b) a curve which tends to flatten out, but still rises, if only very slowly, for quite high fishing rates, and has no clear maximum.

For fisheries with a type (a) yield curve there can be large benefits if the stock is overfished (e.g. at point A) by restricting fishing and thus increasing the catch; these benefits will occur whether or not the reduction of the amount of fishing allows a reduction in the costs of fishing. In type (b) curves there can be no increase in catch, but there may still be benefits, possibly considerable, if costs can be reduced.

The potential benefits may be seen more clearly if, taking a more representative curve, such as (c) in Figure 1, the fishing mortality is expressed in terms of the cost of fishing, and the catch in value. To a first approximation, if nothing is done to affect the efficiency of fishing operations, total costs will be proportional to the fishing mortality, and the value of the catch to the total weight. This latter assumption ignores, inter alia, the fact that with increased mortality the average size, and hence often the price per kg, will be lower. Also with fewer age-groups present in the catch, year-to-year fluctuations due to year-class variations will be more pronounced which may also tend to reduce the value of a given average annual catch. The assumption is also implicitly made that the elasticity of demand is unity, but since an increasing proportion of fishery products are being supplied to a comprehensive world-wide market (fish meal, shrimps, frozen fish sticks, etc.), changes in the supply from a single stock can make little difference to the price.

A curve relating costs to value, such as Figure 2, can then be derived. Also shown in Figure 2, is the line of equal costs and value. In the absence of regulation fishing will tend to stabilize at the point P where the line cuts the curve.1/ If in the example of Figure 2, fishing is reduced to give the maximum catch, point Q, then there will be some benefit from the increased catch (QX), but there will also be a benefit (PX) from reduced costs - provided the efficiency is not altered. Often, as in the figure, this benefit can be greater than that from increased catch. Also, if the fishing is further reduced, say to R, then the further reduction in costs (RY) is possible which will be considerably greater than the reduction in value (QY). For fixed economic conditions a point giving the maximum net economic return (value less costs) can be defined. Since economic conditions do vary this point is not absolutely fixed, and cannot be used as the uniquely definable objective of fishery management in place of the objective of

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1/ This may be an optimistic view. Many fisheries are now developing very rapidly. Since the stocks may take some time to react to increased fishing, and investment policy is commonly based on past catch rates (at possibly much larger stocks), the fishing effort (in terms of fleet size, etc.) can easily overshoot the equilibrium position and take a long time to return.

FIG. 1

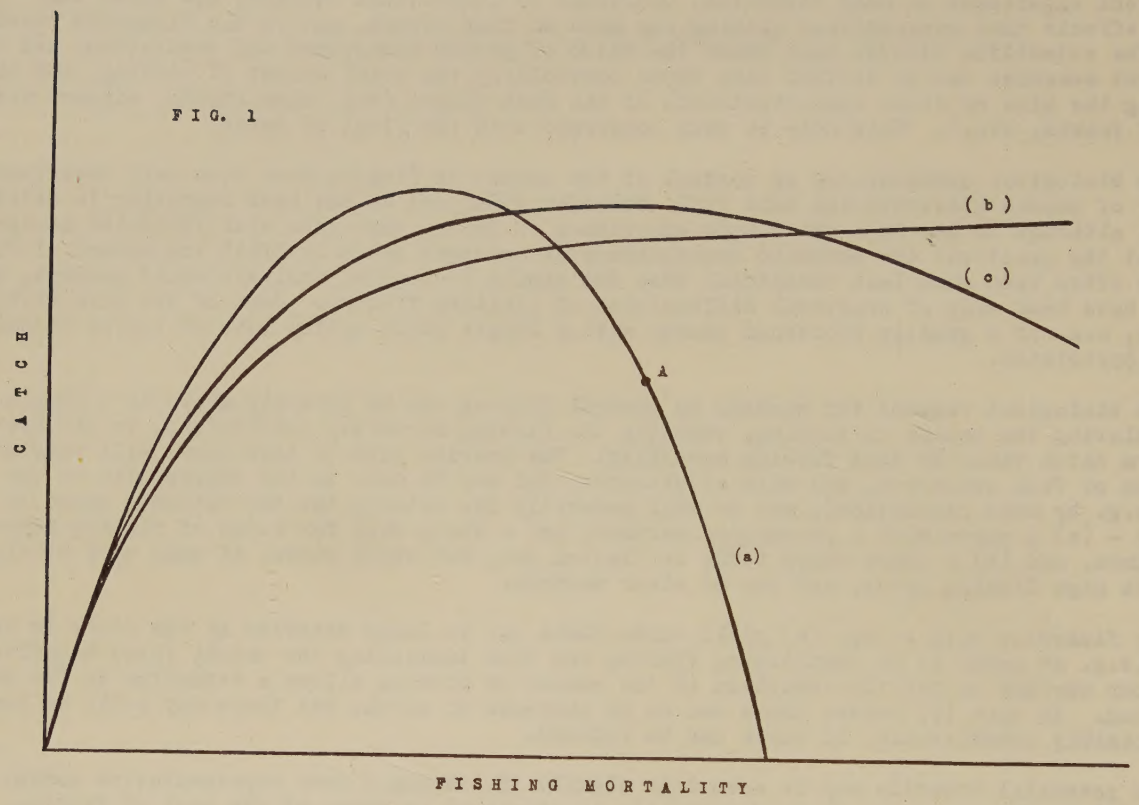
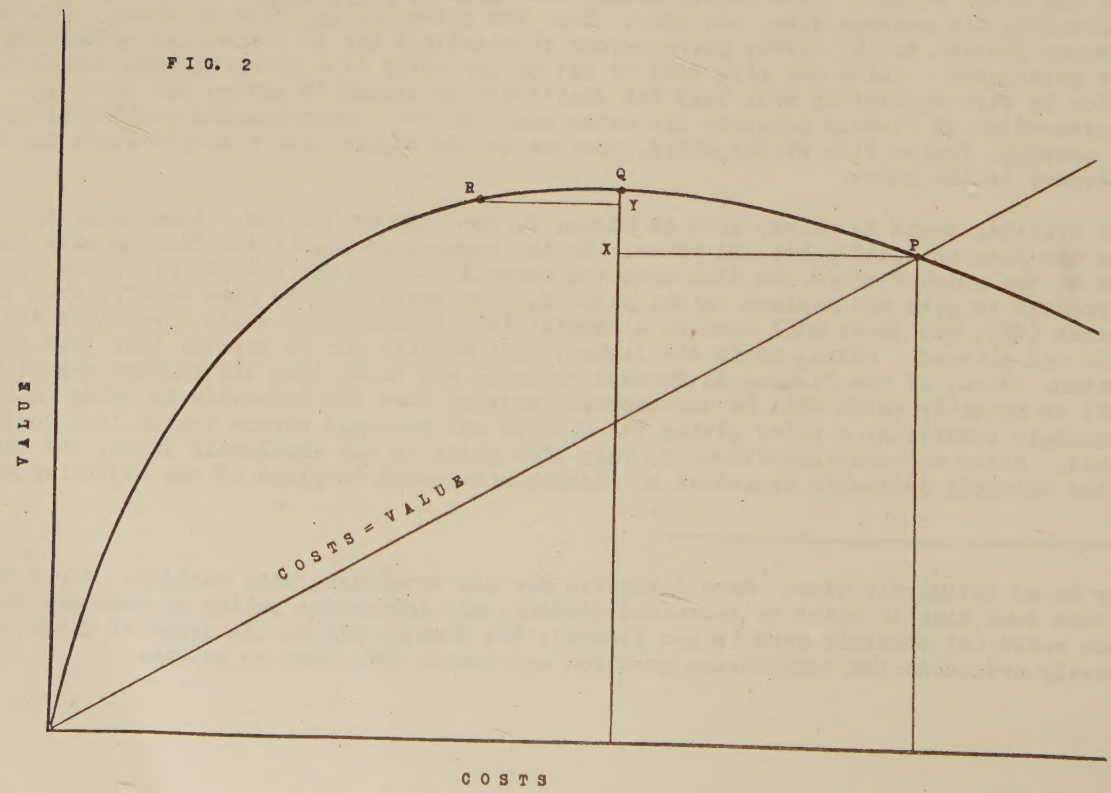

CATCH
(b)
(c)
A
(a)
FISHING MORTALITY

FIG. 2


VALUE
R
Q
Y
X
P
COSTS = VALUE
COSTS

maximum physical yield which also has both biological and economic shortcomings (Gulland 1968). However it will always be true that in all situations (with a few trivial exceptions) it is desirable on economic grounds to fish at less than the rate giving the maximum physical yield.

The close interrelation between biology and economics, and the economic implications of the presence or absence of regulations, using the same or similar arguments to those above, has been recognized by biologists for at least 30 years (Graham 1935, Beverton 1953) and have more recently been forcibly pointed out by a number of economists (Crutchfield 1959, Gordon 1954, Scott 1955).

The full benefits of regulating the amount of fishing therefore require the satisfaction of two conditions - reduction of the fishing mortality coefficient, F, to the desired level, and ensuring that this reduction of F is achieved with the minimum loss in the efficiency of the fishing operations.

The preceding analysis assumes that the only variable factor affecting the fish stocks is the amount of fishing, but other, environmental, factors can have big effects. One of these is the variation in recruitment, the number of young fish reaching commercial sizes. The strength of year-classes (the numbers in each annual brood) can vary greatly and the causes of these variations are not clearly understood. For this reason (among others) scientific assessments are often presented in terms of the yield per recruit; usually the yield per recruit from a given fishing mortality is less effected by environmental factors than is the yield.

These natural fluctuations cause the desirable catch (on almost any criterion) to vary from year to year, but the desirable fishing mortality e.g. that giving the maximum long-term yield in weight, is more constant. However, a fishing mortality which is the optimum when year-class strengths are average may be too high when weak year-classes are present in the fishery, since it may result in too low a spawning stock; it may therefore be necessary to reduce the fishing mortality when year-classes are poor, and possibly to increase it when good year-classes are present. This agrees with economic considerations - it is worthwhile to incur extra costs to get a bit nearer the maximum physical yield when this yield is large. This effect is in addition to the increase in total yield which will occur, even for a fixed fishing mortality, when a good year-class occurs, and which may require a bigger vessel or shore capacity to handle it.

2. MEASUREMENT OF FISHING MORTALITY

The fishing mortality (F) cannot be easily measured, at least over a short period. Control of F is therefore achieved by controlling some other quantity which is more easily measured and therefore controlled. The choice lies between catch (C) and fishing effort (f), e.g. total number of boats times the duration of fishing, which are related to fishing mortality by the two equations:

$$C = B \times F \quad \ldots\ldots\ldots\ldots\ldots (1)$$

$$F = qf \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where B = abundance of the population and q = catchability coefficient

The implicit assumption made in controlling fishing mortality in terms of catch (or effort) is that B (or q) is constant, or that changes in B (or q) are known. Changes can be of two types - essentially random fluctuations, and trends. Particularly with long-lived species year to year fluctuations may not be very serious, even if not predictable. If the mortality in one year is high, because weak year-classes are present (for a fixed catch) this can be balanced by reduced mortality (lower catch or nominal effort) in the next, provided there is adequate administrative machinery to detect the occurrence and to make the necessary adjustments to the permitted level of catch or effort.

One major source of changes in population abundance - varying strength of year-classes - has been noted above. Typically a year-class enters the fishery when from one to five years old, and can make a substantial contribution to the catches for the next two to ten years. Forecasts of the abundance of the stock in one year can therefore be made from the information on the abundance and age composition of the commercial catch in the previous year, and these predictions will include all but the youngest fish. These can often also be predicted by research surveys of young fish, e.g. by the trawl surveys of young cod in the Barents Sea, and for long-lived fish quite accurate forecasts of abundance (excluding the effects of the removals by fishing) can

therefore be made for several years in advance. The main practical problems are: first of providing the necessary machinery for rapid analysis of one season's results (catch rates, age composition, etc.) and subsequent adjustment of the permitted level of catch in subsequent seasons; and second, obtaining adequate estimates of the strength of year-classes among the youngest fish; if year-class strengths vary greatly and the fish are in the fishery for only a short time so that the strength of the year-class newly recruiting to the fishery can have a big effect on the total abundance, these latter estimates may have to be quite accurate and may require extensive surveys by research ships of the pre-recruit fish.

Even if natural (non-fishing) factors cause little change in abundance, a fixed catch limit can be very dangerous. The catch quotas set by the International Whaling Commission in the period after the Second World War (15,000 - 16,000 Blue Whale Units) were initially only just greater than the combined sustainable yield of the two main species (blue and fin whales). However, as the catches were too high, the stocks declined, and the nearly constant catch quota resulted in fishing mortality rates which exceeded the desirable rate to a greater and greater extent.

The control of the amount of fishing in terms of fishing effort would in principle prevent this happening. Thus, in the Antarctic, the number of catchers and the length of the season both increased during the period as the industry had to work harder to maintain the total catch. A limit on the number of catcher-days would thus have apparently kept the fishing mortality closer to the near-optimum level of 1946/8. However, even under the existing (catch-quota) regulations the power and efficiency of the catchers increased, and the enforcement of a constant number of catcher-days would have still permitted some rise in fishing mortality. In fact, it is very probable that regulation in terms of catcher-days would have in later years accelerated this process. Since 1962, there has been an agreement between the countries concerned to divide the overall quota. If this division had been in terms of effort, i.e. in numbers of vessels or of catcher-days, it would be greatly in the interests of each country to increase the catching power of its vessels, and hence increase the fishing mortality caused by its fixed share of nominal effort. The total fishing mortality would thus have increased beyond the desired limits. A better control of mortality could be achieved by the use of a rather more complex measure of effort, e.g. catcher days x gross tonnage of catcher, but it is unlikely that any simple and readily controlled measure of effort would take into account all the increase in catcher efficiency.

The control of mortality through effort control, e.g. in terms of number of days fishing, is subject also to other difficulties similar to those incurred when controlling mortality through catch, with additional difficulties due to the need for inter-calibration of effort statistics. The catchability coefficient, q, is no more likely to remain constant than the population abundance, so that measurement of fishing mortality in terms of fishing effort presents similar problems as the measurement in terms of catch. The variations in catchability coefficient, like the variation in population abundance, have to be measured, and, so far as possible, predicted. These variations have two groups of causes - natural and man-made. Generally natural fluctuations in catchability or "availability" are less violent than year-class fluctuations, but can be quite large. For example during cold winters in the North Sea soles can be much more easily caught than normally - an increase of several times in the fishing mortality per unit fishing effort; control in terms, say, of the number of hours fishing could allow serious overfishing during a prolonged cold winter. Thus the winter of 1962/3 was doubly disrupting to the sole fishery - over supply during the winter, with a drastic fall in prices, followed by a shortage of fish in the summer, due to previous unusually heavy exploitation (and also unusually high natural mortality due directly to the cold).

Man-made changes in q can be larger, and will have more serious consequences on attempts to control mortality. Any statistics that can be readily collected concerning fishing effort will provide only an approximate measure of fishing mortality. For some gears, e.g. long-lines, an available unit of effort - e.g. the number of hooks times the number of sets made - may bear a fairly constant ratio to the mortality caused and improvements in fishing technique will be such as to increase the number of hooks set per boat or per man, rather than in the mortality caused by 100 hooks. For other more active gears, such as trawls or purse-seines (which take a major and increasing share of the world catch), the measure of both fishing power and fishing time (fishing effort equals fishing power multiplied by time) is less certain. For purse-seines (and increasingly for trawls, especially fished in mid-water), much of the time is spent searching for suitable concentrations of fish. Improved equipment (e.g. echo sounders, sonar) is continually increasing the effectiveness of an hour or a day spent searching.

Similarly the real fishing power of the average vessel in a fleet is being continually increased by building larger vessels, with more powerful engines, improved gear, etc. Some correction for this is possible by taking into account the various characteristics of ship and gear. This calibration is particularly useful in analyzing past data, especially when the introduction of new gears, or new ships, has taken place over a period. Thus several analyses have shown that, in a particular year, catches (and therefore the mortality caused) by trawlers of different sizes are proportional to both gross tonnage, and horse-power of the engines (Beverton and Holt 1957, Gulland 1956). This result is important when the average size, or power, of the ships in a fleet is increasing, but does not show whether these have been increasing in real fishing power of a vessel of a given size from one year to the next.

Such difficulties will exist in any fishery, but will be redoubled if the control of mortality involves any allocation. Then it will be greatly to the interest of each person receiving an allocation, presumably in the form of so many units of effort, to ensure that the mortality caused by his units (and hence the catch taken) is maximized.

The simplest case is a fisherman with a licence to operate one trawler; he will then build the biggest one feasible. This might be controlled by limiting the size to so many gross tons; then a bigger engine would be fitted. In turn the nominal horse-power might be controlled, but the engine run flat out (the extra catch making up for increased maintenance and replacement costs). Though the framer of the regulations may catch up with the ingenuity of the fisherman, it is more likely that the latter will keep one jump ahead. In any case, the vessel and gear and the methods of operations will be designed more to maximise the catch within the limits of nominal effort set by the regulations, than to maximise the catch from a given total of costs or to minimise the costs of taking a certain catch. To this extent the fishery will operate at less than its possible efficiency, and the magnitude of this inefficiency is likely to continually increase.

Changes in q, through improvements in gear, etc., will thus affect the total fishing mortality caused. If precise calibrations cannot be made, it may be possible to make reasonable forecasts of the likely increase in efficiency, q, for the fishery as a whole and take this into account when setting the limit to the total effort. For instance, if the efficiency is likely to increase at 3% per year, then the total allowed nominal effort should be reduced. However, in any complex fishery, involving several fleets using different gears, or different types of vessel, it is most unlikely that the improvements in gear changes in q, will be the same for all segments of the fishery. Therefore, the above adjustments, reducing the overall effort quota by, say, 3% per year to allow for the average increase in efficiency, while maintaining the fishing mortality at about the desired level, will not ensure that the shares taken by different segments of the fishery remain the same. This can be done only by determining the change in q separately for each group of vessels. In this, as in other matters, justice must not only be done, but also be seen to be done. For example if there are two fleets, trawlers (with effort controlled in terms of ton-days - tonnage of trawler times days at sea), and long-liners (number of hooks times frequency of use) it is almost inevitable that the long-line fishermen will suspect the trawlermen of achieving a greater increase in efficiency than is accounted for by any increase in tonnage, while the trawlermen may claim that their fishing power has gone up less than the tonnage. Conversely there will be suspicions that the fishing power of long-lines is not properly measured by the number of hooks. A related aspect of this is that the more precise measures of fishing effort rely on statistics of fishing time (e.g. number of hours spent fishing - with the net on the bottom in the case of trawls) which have to be provided by the fishermen (e.g. in log books) and cannot be easily checked independently. ("Black boxes" are being developed which, attached to an otter-board can record the depth and duration of each haul, but these are still a research tool). Also many of these log-books and other records provide one of the fundamental bases for the scientific study of the stock. If the form of the regulations encourages the falsification of the records, the research will suffer.

The basic check on whether two fleets have maintained the relative magnitudes of the fishing mortality caused by each is the ratio of the catches. For any year, or fishing season, the mean abundance B of equation (1) has a single value, applicable to all fleets, i.e. denoting the catches and mortalities caused by two sections of the fishery by subscripts

$$C_1 = B \times F_1$$

$$C_2 = B \times F_2$$

whereas the corresponding forms of equation (2) are

$$F_1 = q_1 f_1$$

$$F_2 = q_2 f_2$$

where q_1 q_2 may have very different values, and vary in different ways from year to year.

For example, if in the base period of a management programme two fleets have taken equal catches, then they will have reduced the mortality caused by them to the same extent in some later year if, and only if, their catches are also equal in that year. There is an exception to this, if during the period taken as a unit for regulation (normally a year) there are big fluctuations in the population abundance (not availability) and in the time of operation of the two fisheries, so that it is not correct to take B as the same for both. An example of this is a gantlet-type fishery, e.g. of fish going upstream to spawn, with two fisheries at different positions in the migration route. In such a situation management practice is best formulated in terms not of fishing mortality but of the percentage of the stock starting on the migration. Then relative catches would again be the best measure of the relative percentages taken by two fisheries.

It appears therefore, that in a fishery in which several groups of fishermen participate, fishing mortality is best measured, and the targets of regulation set, in terms of catch. This is indeed what has been done in all the major international agreements concerned with limiting fishing on single species or groups of closely related species - c.f. Pacific halibut, Antarctic baleen whales, eastern Pacific tuna, Pacific salmon, etc. Only where a complex of species is concerned has some measure of fishing effort been used, c.f. controls on the number of vessels under some of the agreements concerning the bottom fisheries in the East China Sea.

The choice of the measure used to set a limit to the amount of fishing is only the first step; the second, and more difficult, is the choice of the control mechanism to ensure that this limit is not exceeded.

3. CONTROL OF FISHING MORTALITY

Whatever indirect measure of fishing mortality is used, there remains a choice in the way the amount is controlled. If the mortality is higher than desired, then the amount can be reduced in several ways:

(i) stop everyone from fishing for some of the time

(ii) stop some people from fishing for all the time (limited entry)

(iii) allow all to fish all the time (or most of the time) but limit the efficiency of operations

(iv) some combination of these

The third of these clearly prevents the costs of fishing to be reduced in proportion to the reduction of fishing mortality, and thus loses much of the possible benefit of regulations. However, in one form or another (prohibitions on trawling, on the use of monofilament gill-nets, limitations on the size of ship) such methods have been widely used, especially in national programmes of fishery management.

Restrictions on gear efficiency may be of value when other regulations giving greater economic benefit cannot be employed. For instance, whenever the yield/effort declines sharply beyond some maximum point (e.g. in the simple Schaefer model, or when the recruitment is significantly reduced by reduction in adult stock), there will at least be a gain in total catch by preventing the mortality increasing beyond the value giving the maximum.

There may in some circumstances even be some economic benefit in restricting the type of gear in comparison with having no regulations at all. Suppose a group of fishermen is fully exploiting a stock of fish, and that they have no easily available alternative employment. A new method of fishing - e.g. with purse-seines instead of gill-nets - might give improved efficiency

and for an individual fisherman his increased catches would (so long as the others used the old gear) greatly exceed the additional costs of the new gear. However, if all use the new gear (and if one starts the others will have to follow), the long-term effect will be that the same total catch is shared among the same people, who will have the extra costs of the new gear.

The prohibition of the use of the most effective gear may therefore be better than doing nothing, though less desirable than allowing the most effective gear with other methods of regulation - unless the objectives of regulation are, for example, to maximise employment until those displaced can be fitted into other jobs. This method will not be discussed in more detail here.

4. SINGLE QUOTA REGULATIONS

The first method (no fishing by anyone for part of the year) or "single quota" system is at present the most widely used form of control in international fisheries. Since it is often associated with a predetermined catch quota (e.g. in Antarctic whaling, or yellowfin tuna in the East Pacific), it has sometimes been treated as being identical with control in terms of catch rather than effort. In principle, there is no reason why the single quota should not be defined in effort units - e.g. the quota for the yellowfin might be set at an effort of 30,000 standard days, rather than at a catch of 100,000 tons, fishing stopping when the effort quota is expected to be reached. Conversely, as discussed below, the amount of fishing can be controlled in terms of catch without necessarily involving a single quota system.

The system has some clear advantages. It is non-discriminating - or at least if there is discrimination, e.g. giving some advantage to those who can get the bigger share of the quota while the season lasts, the regulatory body is not explicitly involved in making a discrimination, i.e. between those who can fish, and those who cannot, or in determining the share of those who can. It is also comparatively easy to enforce. During the open season there are no restrictions, and there is little incentive for the misrepresentation of total catch, or other statistical data - e.g. of fishing effort, or exact location of catch, both of which are important elements for scientific study of the stocks. A complete prohibition of fishing during the closed season is much easier to police than a partial closure, with fishing permitted to only certain fishermen. It is even easier if the number of landing places is restricted, and the control is expressed in terms of landing rather than catching. Thus the season for the yellowfin tuna is in terms of landing as a function of sailing date - those vessels sailing before the closing date can land unlimited yellowfin, those sailing later can only land small quantities of yellowfin (up to 15%) among their catches of skipjack or other unregulated tunas. There is no limit to the period or amount of fishing by the first group, until they have filled their holds, and land the fish; nor is there an explicit control of fishing by the second group, provided they land no more than 15% yellowfin; the timing of the end of the open season takes these two elements of yellowfin catch into consideration. On the first appearance the enforcement of the regulations needs no more than routine inspection of the landings, but there are two complications, both of which are examples of general complications arising in any application of the method.

The first concerns fishing for yellowfin tuna outside the area covered by the regulation. Unless fish from the two stocks can be clearly distinguished on the fish market (and ultimately perhaps in a court of law) the landings of fish outside the open season are not evidence of a breach of the regulations. Undoubtedly, fishermen wishing to fish in the closed season will be tempted to do so and claim that the fish came from outside the regulation area. Thus there has been a large rise since regulations were introduced by I-ATTC in yellowfin catches reported to have come from the western region just outside the Commission regulatory area. Of course some, or indeed possibly all, may truly be taken by vessels moving to these unregulated stocks, though a degree of deliberate misreporting is very likely. Unless all stocks of the same species can be adequately managed by the same closed season, some enforcement and inspection at sea - which adds greatly to the administrative costs - is therefore inevitable. In the case of the I-ATTC these costs are passed to the fishermen by requiring them to carry an independent qualified navigator as observer if they wish to fish yellowfin west of the regulated area. However, the management requirements of separate stocks are unlikely to be the same; for instance, the surface living shoals of yellowfin tuna are heavily exploited in the East Pacific, becoming heavily exploited in the Atlantic, but are as yet almost untouched in the Indian Ocean. A lack of balance between the exploitation of different stocks is likely to be increased by a single closed season; as this becomes shorter the attraction of the grounds nearer port (allowing more trips within the open season) become greater. The stocks on nearer grounds thus become increasingly over-exploited, while those further away are neglected. In the Pacific halibut fishery this process has occurred and has been countered by a more complex regulatory season, involving different seasons for

different grounds.

The other complication concerns other species which may be caught simultaneously, or with the same gear, in the regulation area, e.g. skipjack tuna in the I-ATTC regulatory area. The problem of joint regulation of several stocks is discussed in detail later, though it may be noted here that only rarely can a species be considered in isolation. The I-ATTC is concerned with obtaining the maximum sustainable yield of all tunas - not with that of yellowfin alone (the question of whether in any case the maximum sustainable yield is or is not a proper objective of management is not discussed here). Therefore, the Commission has failed to reach its objective so long as the skipjack stock (or stocks) remain under-exploited, even if the maximum yield of yellowfin is being achieved; regulations to maintain the yellowfin catch at the desired level at best only partially serve the Commission's objectives if they tend to inhibit increased fishing of skipjack (so long as skipjack remain under-exploited). Specifically fishing skipjack should be allowed during the closed season for yellowfin.

Inevitably, since the species may be mixed, or misidentified in the water, some yellowfin will be caught while fishing for skipjack. If these cannot be landed, they will be wasted, since few if any will survive if dumped back into the sea - also the incidental catches of the higher priced yellowfin make the skipjack fishery more attractive. Therefore, a certain percentage of yellowfin has had to be permitted - similarly a percentage of "protected" species (cod, haddock) are allowed in the North Atlantic trawl fisheries for herring, etc., using a mesh size below the normal regulation minimum size. Based on observations in the pre-regulation period a limit of 15% yellowfin was set. The result has been that most fishermen have, in order to maximise the value of a load, set this as a normal target, catching yellowfin up to 15% of their total capacity early in their trip. Inevitably some more yellowfin are taken later in the trip and have to be dumped and wasted. Some measure of the extent of this was reported at the 1969 meeting of I-ATTC, when the dumping in 1968 was stated from log book records to have been appreciably greater than in 1967. Only exceptionally are the interests of the management in the regulated species given high priority over the development of the fisheries of other species. One exception is the Pacific halibut; not only are there restrictions on the gear used in halibut fishing (only long-line), but there is a prohibition on landing halibut caught incidentally in other gears. Halibut are tough fish, so that discarded halibut may survive, especially if returned to the sea quickly, though to what extent this is done in commercial practice is uncertain.

A major economic disadvantage in a single quota system is that there is no control of the size or fishing capacity of the fleet. (Fishing capacity may be defined, in the sense used here, as the fishing mortality that could be exerted by a fleet of vessels if it operated without restriction). If the regulations achieve their objective in increasing the stock and the catch rates, and so make fishing more profitable, additional ships will be attracted into the fishery. The enlarged fleet will reach the desired catch quota more and more quickly, so that the open season becomes shorter and shorter. This effect, readily predictable in theory, has been observed in most fisheries where a single quota system of regulation has been used - e.g. the Antarctic baleen whaling, where, prior to the agreement on the division of the quota, the season had been reduced rather steadily from 121 days in 1945/6 to 58 days in 1955/6. More recently, in the first three years of effective regulations of yellowfin tuna fishing in the East Pacific, the length of the open season has been reduced to 3½ months.

This shortening of the season will add to the costs of fishing. The extent will depend on the relative magnitudes of the different costs - capital costs of ship and equipment; running costs; and crew costs - an also on the degree to which some of the fixed costs can be spread over alternative operations during the closed season. For instance, there is little alternative for whaling ships, but tuna vessels can fish for skipjack or move to the Atlantic and fish for yellowfin there.

The long-term result will be that costs will rise with the shortening season until a new equilibrium position is reached, as before regulation, in which the costs of fishing are equal to the value of the catch, and the potential economic benefits of the regulation are lost. Therefore, if the economic benefits are to be obtained the alternative system - preventing some people from fishing for all the time - need to be considered, either as the sole method of regulation, or as a modification to the simplest form of single quota system.

5. ALLOCATION OF SHARES

Limitation of the right to fish to certain individuals or groups - limited entry - involves, in any international fishery, two successive problems of allocation - between countries and within countries.

It should be noted here, that if any country wishes to introduce a scheme of entry limitation among its own fleet, this is only practicable - unless it is the sole, or predominant country fishing on the stock - if there is a system of allocation between countries. The converse is, however, not true. If shares of the total (in catch or effort) are allocated to countries, this in no way necessitates that any individual country operates a limited entry system on a national scale. One of the attractions of a system of allocating national quotas is that it does allow countries a wide flexibility in national regulations, provided that they ensure that the national share is not exceeded, e.g. a nation may set its own single quotas regulation for its national fishery. This flexibility is obviously important in allowing a variety of countries with very different social, political and economic conditions (e.g. Spain, Germany, Canada and USSR in the Northwest Atlantic cod fisheries) to pursue their varying national objectives.

The problem of allocating a limited amount of fishing (whether in terms of a number of licences for vessels, or catch quotas), is best approached in terms of deciding the use to be made of the potential economic benefits. Two obvious beneficiaries can be identified - the national treasury, and those presently engaged in fishing.

The first of these would benefit if licences were temporary - for one or a limited number of years - and issued at a high fee. This licence fee should be so high that the less efficient fishermen cannot afford to pay it, and the number of applicants for licences (the more efficient fishermen) are just equal to the number of available licences. In practice social and other factors, other than simple economics, may be taken into consideration when issuing licences. Thus the licence fees might be somewhat reduced, so that the number of applicants would likely be greater than the number of available licences. The choice between these applicants would then be on a basis of these other factors. If allocation were done purely on economic criteria, and licence fees were as high as possible - which might be achieved by an auction system for licences - the total licence fees should be about equal to the difference between the value of the catch and the minimum cost of harvesting it (here and elsewhere in this paper costs are understood to include a reasonable return on investment on vessels, etc., as well as running costs, wages, depreciation, etc.).

The second alternative, of benefit accruing to existing fishermen, could be achieved if licences were permanent but transferable. As the fish stocks build up under regulation the right to fish acquires value, which should be reflected in the increasing capital value of a licence. In the long run the total capital value of all licences should be such that the interest from it, if put into alternative investment, would be equal to the difference between the value of the catch and the cost of harvest.

In both, problems arise in relation to the measure used of fishing mortality, and in the transition period from a heavily exploited unregulated fishery to one in which the fish stocks have been built up by the management. These problems are less when licences are limited in duration and have a high cost, so that allocation is decided by the ability to pay the fee. There is then no real difference between the long-term and transition period, except that the possible fees will be smaller during the transition period - and probably negligible in the first year - while the stocks are being rebuilt. Also in the transition the net amounts going to the national treasury may be smaller because part or all may be used to give temporary compensation to those fishermen failing to get licences or to resettle them in alternative employment.

Provided mortality is measured in terms of catch, the choice between different sizes or types of vessels is straightforward - the fishermen operating the most efficient vessels (those that can land fish at the least cost), will be best able to afford a licence. If licences are in terms of vessels, then there will be problems of determining the appropriate fee to operate a 150 ton trawler, if the licence to operate a 100 ton purse-seine vessel costs, say, $10,000.

The justification of using the vessel rather than catch as a basis for licencing, is that the vessel is the natural basic operating unit. The practical advantages of vessel licences, rather than a licence to catch a certain quantity, are particularly marked when the fishing industry is composed of a large number of separate units - especially skipper-owners - rather than a few big concerns. A large concern operating a number of ships can adjust the number to

its catch quota, making adjustments if necessary towards the end of the season; most of the active ships can then work at full capacity throughout the year. A man operating one ship has less flexibility - there is a certain quantity of fish he can catch (or a certain fishing mortality he can cause) if the ship fishes at full capacity - a bigger catch quota cannot be used, and a smaller quota means that the ship is working at less than full efficiency - unless good alternative employment is available. This aspect is not confined to small operations; one of the problems facing the Norwegians in Antarctic whaling as the quota was reduced, was that in some seasons their share, based on a fixed percentage of the total, was too large to be harvested by a single expedition (factory ship plus associated catchers, supply ship, etc.), and too small to support two expeditions.

If the number of licences is controlled, or more strictly, if the number of those applying for a licence is limited, by charging a large licence fee, the relative magnitude of the fees paid by vessels of different types or size has to be carefully decided. On purely economic grounds these should be adjusted to give no artificial advantage to any group, and should allow the most efficient fishing unit to be developed. However, few, if any, fisheries are managed on purely economic (or purely biological) grounds. Social or other considerations can easily be taken into account in setting licence fees. For example, a concern of many governments is to encourage the development of more efficient fishing units, whilegiving protection, during their working life, to groups of existing fishermen with small (and basically inefficient) vessels. The two somewhat conflicting objectives might be achieved by charging properly balanced fees to any new ships, but artifically low fees to existing small vessels. This artifical difference could be abolished progressively over a shorter or longer period in accordance with general social objectives.

If licences are issued for a limited period, the duration of this period can be important to the development of new techniques. If it is too short, then the uncertainty about future operations may inhibit new developments, especially those requiring big investments; too long, and the fishing may stagnate without the effective pressure of those outside the fishery, with new ideas wishing to use them. A reasonable period might be around 5-10 years, i.e. perhaps a half to a quarter of the normal working life of a fishing vessel. Presumably this would be managed by one-fifth, or one-tenth of all licences being renewed each year, rather than all being renewed every 5-10 years. The time of determining licence-holders also needs some consideration. It should be done sufficiently in advance of the period concerned to enable new entrants or others to adjust their construction of vessels and other investment actions in accordance with their holdings of licences.

The basis for issuing licences has been considered so far only in terms of the economics of the particular fishery directly concerned. Consideration should, however, be widened to cover the effects on other fisheries. A limitation, or the need for limitation implies that there is surplus capacity, in money, or ships, etc., that can be used elsewhere - not necessarily in fishing. If one alternative is to exploit another stock of fish that is underexploited, the choice of licence-holders may be made so as to encourage the diversion of the surplus to that stock. This may be done quite explicitly, e.g. a condition of granting a licence to a company may be that it undertakes at least some trial fishing on the new area.

Less direct ways can also be used. For example, if a range of sizes of ships are fishing an inshore ground, which is over-exploited, while more distant grounds are neglected, it may be desirable at first to restrict licences for the near grounds to the smaller vessels (assuming that they can only fish near port), thus forcing the larger vessels to seek new grounds. In the short run, this would increase the economic effectiveness of the fleet as a whole, even if the larger vessels were the most suitable for the nearer grounds, since, if they were allowed onto the nearer grounds, there would be no productive activity open to the smaller vessels. In the long run, however, it would be necessary to reduce the small-ship fleet to that giving the optimum level of fishing mortality, and then gradually to allow the larger ships back into the fishery as replacements for the smaller ships.

If the replacement is merely a matter of changing the ships the process can be moderately quick; no more, at a maximum, than the economic life of a vessel. Often though, large and small vessels belong to quite different groups of fishermen; the change would involve major changes in habits, perhaps of whole communities, and can be very lengthy.

If licences are held for an unlimited period, and are transferable, then the measures of fishing mortality in which they are expressed have to be carefully chosen. A licence to, say,

operate one trawler would certainly offer no restraint on the mortality caused unless there was at least a limit on the size, and, as described above, even this is likely to become ineffective, either by deliberate actions, such as fitting an exceptionally powerful engine, or by normal technological advances. Similarly, a licence to catch any specified quantity would lead to over- (or under-) exploitation, if there was a reduction (or increase) in the stock.

The above discussions outline some of the problems involved in controlling the fishing mortality caused by a national fleet by limitation of entry. While not exhaustive these discussions do suggest that limited entry, by itself, offers a more satisfactory solution to the problem of rational management than a single quota system.

It may be that a combination may be more successful; a single quota system achieves the correct fishing mortality, but gives much less promise of preventing the build-up of excessive fishing capacity. Conversely, limited entry prevents excess capacity, but may not ensure the correct mortality. Under a combined approach the primary control of fishing mortality would be the catch quota, but a licencing system would be used to limit the capacity of the fleet. Since the initial purpose of the licence would be to prevent new entries, rather than cut down the existing fleet, the great difficulties inherent in refusing licences to existing fishermen need not arise. The ultimate objective could be to maintain the fishing capacity a little greater than that necessary to take the quota in a full year, so that, under average conditions, the season would end after around 11 months. The same methods to ensure continuing operational efficiency - transfer of licences, or a high fee - as used in controlling mortality entirely by limiting entry, would be necessary.

While this procedure makes regulation more complex, with two separate processes - setting licence fees to control the fishing capacity, and setting a catch quota to control fishing mortality, this may not be too inconvenient. It also serves to emphasize the two rather separate objectives of regulation - biological, achieved by the catch quota, and economic, by the licence fee.

6. SEVERAL STOCKS

The previous sections have described only the management of one stock, treated in isolation. In reality any regulation will have some effect, direct or indirect, on a number of stocks.

Two situations may be distinguished - several stocks of the same species, inhabiting several areas, and stocks of different species inhabiting the same area, and liable to be caught by the same type of fishing gear. Each can be sub-divided into situations where all stocks are too heavily exploited, and are in need of management, and those where some of the stocks are under-exploited. A full management regime for a region should be concerned with all the potentially exploitable stocks in the region, and in particular the encouragement of fishing on under-exploited stocks is as important as the limitation of fishing on the too heavily exploited stocks.

If several stocks are too heavily fished, the best long-term results would be obtained if each is managed separately, to ensure the optimum fishing mortality on each stock. This may be very difficult to achieve in practice. The numerous cod stocks in the North Atlantic differ in the natural parameters of growth, and probably also natural mortality, and will therefore require different fishing mortality rates. However, with the existing long-range vessels fishing in the North Atlantic, which may exploit several stocks in the same voyage, enforcement of separate controls for each stock would be very difficult. This problem was discussed by the ICNAF Bio-economics Working Group (ICNAF 1968), which concluded that since virtually all the cod (and also haddock) stocks were too heavily exploited, a combined catch quota, for all cod and haddock stocks in the North Atlantic would be the most feasible management action, and one that would be much better than the only other practicable alternative - to do nothing.

Some ways in which a single overall quota could be modified to produce a better balance between the amount of fishing on different stocks were examined by the group. In an appendix to the ICNAF report, Gulland described the use of closed seasons to divert effort, within a limited total, from the most heavily fished stocks to those that were only slightly over-exploited. Modifications of the closed season were suggested to allow for ships that are not mobile, and cannot move from area to area. These could receive a share of the overall quota, but specified for a particular stock; within this stock quota fishing by short-range vessels would be unaffected by a closed season.

Another way to differentiate between stocks, particularly if there is an allocation of quotas to individual enterprises, is some form of weighting system. The best known of these is the Blue Whale Unit, used by the International Whaling Commission. Under this, the catch limit was expressed in BWUs, equal to 1 blue whale, 2 fin whales, 2½ humpback whales, or 6 sei whales. These ratios were based on the relative oil yields of the individual species. This system did not prevent successive over-exploitation of first the blue and humpback whales, and then the fin whales, while the other species were initially under-exploited. So long as the quota remained unallocated, as it was between 1946 and 1960, any other weighting system, e.g. for 3 fin whales to be counted as equal to 1 blue whale, would have changed the date of the close of the season (which might have a very marginal effect on the balance between species), but not the tactics and species preference of an individual gunner, or manager of an expedition. If quotas are allocated, then a gunner may prefer to kill a blue whale (if he can), in preference to two fin whales, but prefer three fin whales to one blue whale. In 1955, blue and humpback whales were heavily exploited, the fin whale stocks were at about their optimum level, and sei whales were untouched. If, at that time, quotas had been allocated, and expressed in Whale Regulation Units, 1 unit being equal to ½ blue whale, 2 fin whales, 1 humpback and 10 sei whales, the effort would have been directed away from the over-exploited stocks towards the fin whales, and especially the sei whales. That is, a better distribution of effort would be achieved if the weights given to each species depart from the relative economic values and give more weight to those stocks which are over-exploited.

The same approach seems possible, though has not yet been adopted, for fish stocks, either for similar species, or for stocks of the same species in different areas. There would be an enforcement problem in the latter case, if say cod from West Greenland counted as 1.2 times cod from Labrador, since a fisherman would try to claim that all his catch from West Greenland.

If some stocks are still under-exploited, e.g. skipjack tuna in the East Pacific, the major short-term problems concern the catches of the species being managed, e.g. yellowfin tuna, made by ships fishing for skipjack when they are not allowed to fish for yellowfin - outside the season, or because they have no licence. The simplest solution, adopted by the International North Pacific Halibut Commission, is to ban the landing of such incidental catches. This removes any incentive for the fishermen to fish where halibut are abundant. It has, however, two big disadvantages. First, some incidental catches are often inevitable; the fisherman's first responsibility is to his gear and to his marketable fish, so that when the protected and unmarketable fish are returned to the sea, even the toughest is likely to be dead. These incidental catches are therefore a complete waste. Second, even if the incidental catches are small, they may still make the difference between a good trip and a bad trip; a ban on landing them may inhibit the development of the fishery on the under-exploited stocks. Thus the ban on landing trawl-caught halibut probably slowed down the development of the trawl fishery in the northwest United States, while the allowance of 15% yellowfin in skipjack landings outside the yellowfin season has helped the development of the skipjack fishery.

The tuna regulations of I-ATTC are an example of many under which the problem has been resolved by allowing a certain percentage of the protected species in the landings. However, as explained before, it seems that in this fishery the higher value of yellowfin causes the fisherman to deliberately seek yellowfin during the early part of their trip, thus ensuring their allowed 15% and if more yellowfin are caught later (while looking for skipjack) these have to be discarded and wasted. In other fisheries, however, the percentage allowance may eliminate this form of waste.

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